COMPASS experiment

status and results

On behalf of COMPASS collaboration

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LBNL

Outline

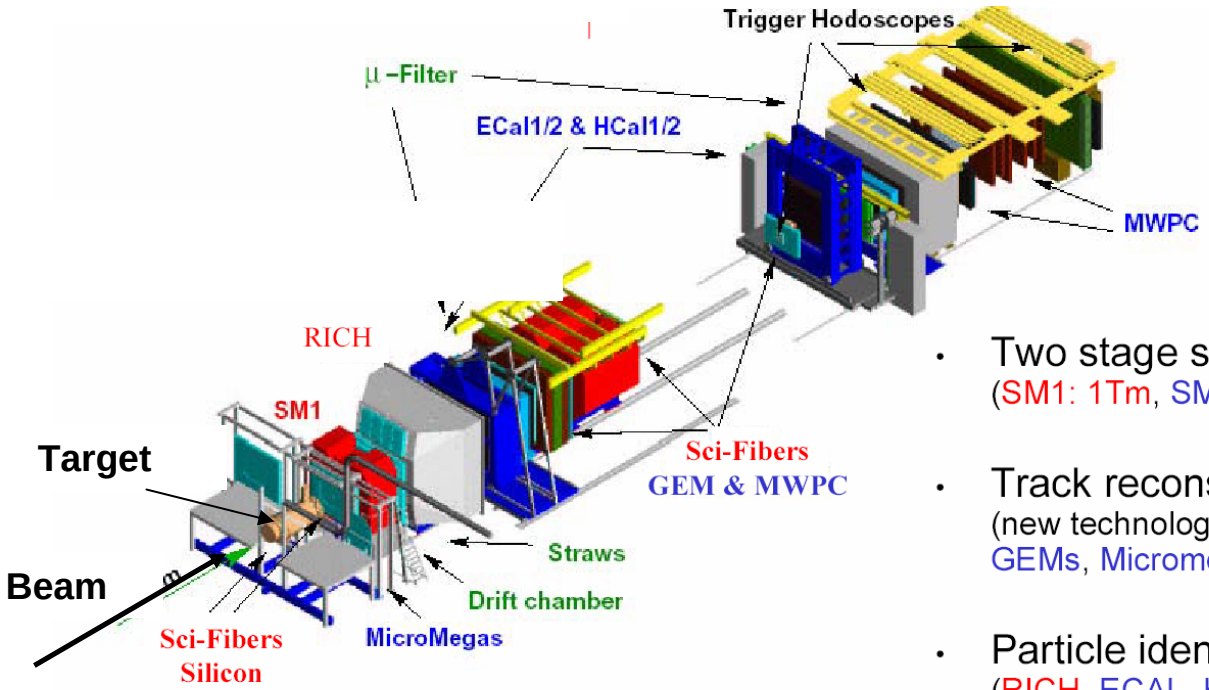
This talk is focused on muon program results from 2002/2003 :

- Collins and Siver asymmetries
- Inclusive asymmetry A_1^d
- Gluon polarization
  - Open charm production
  - Production of high-pt hadrons

Status of hadron program

→ in 2004 first data was taken with hadron beam

COMPASS spectrometer



- Two stage spectrometer
  (SM1: 1Tm, SM2: 5.2 Tm)
- Track reconstruction
  (new technologies: Sci-Fibers, GEMs, Micromegas, straws)
- Particle identification
  (RICH, ECAL, HCALs, μFilters)

Beam:

160 GeV μ^+, polarization P_μ~75%

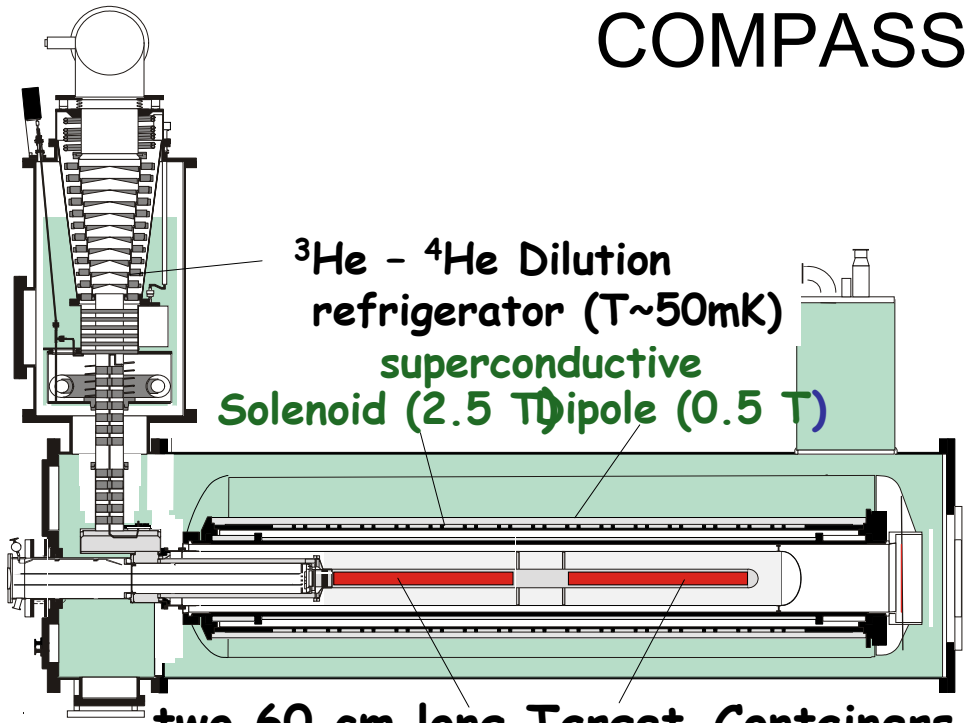
Target:

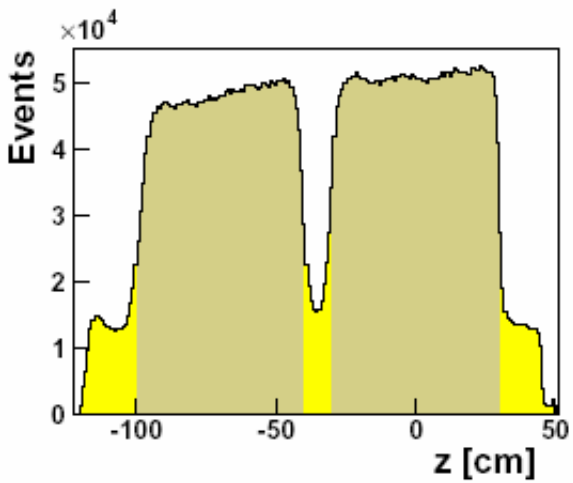
^{6}LiD target, max. polarization P_T~57%

longitudinal and transverse polarization

	2002	2003	2004
Days	70	83	106
Integrated Luminosity (fb^{-1})	1	1.2	~2.4

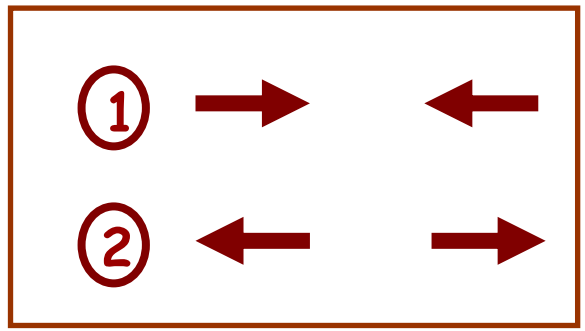
COMPASS target





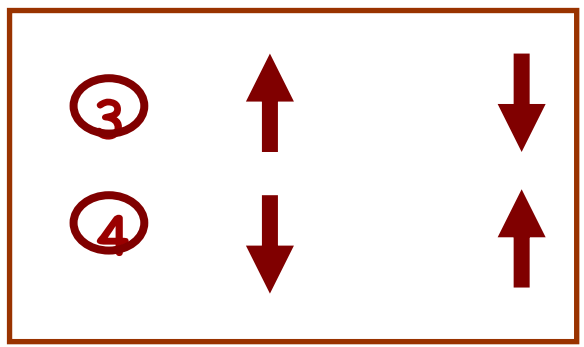
Longitudinal configuration

Reversed every 8 hours



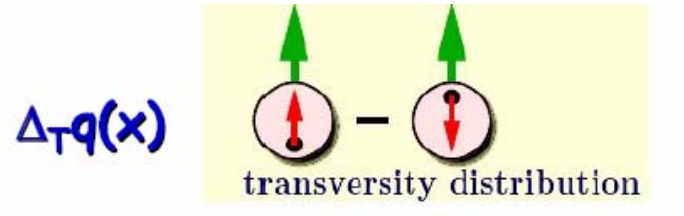
Transverse configuration

Reversed once a week



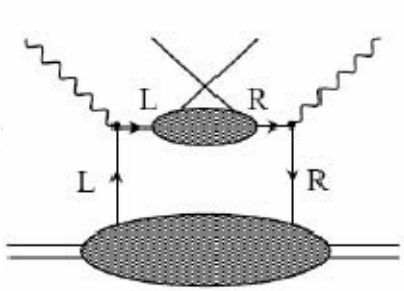
Transversity distribution

Idea:
transverse nucleon polarization
carried by quark



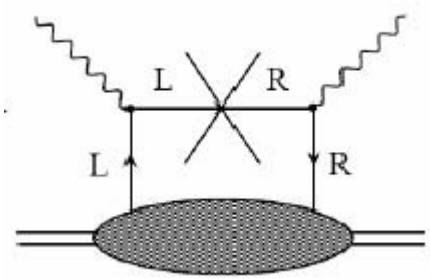
In analogy to longitudinal configuration:

QCD preserves helicity



Inclusive DIS not sensitive

$h_1(x)$ requires helicity flip



Semi-inclusive reactions (SIDIS)

$$\Delta_T q(x) \otimes FF$$

Transverse spin effects

Sivers effect

Azimuthal asymmetry caused by intrinsic k_T dependence of quark distribution in the transversely polarized nucleon

$$A_{Siv}^{\sin\Phi_{Siv}} = \frac{\sum_q e_q^2 \cdot \Delta_0^T q \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

Collins effect

Azimuthal asymmetry in quark fragmentation

$$A_{Coll}^{\sin\Phi_{Coll}} = \frac{\sum_q e_q^2 \cdot \Delta_T q \cdot \Delta_T^0 D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

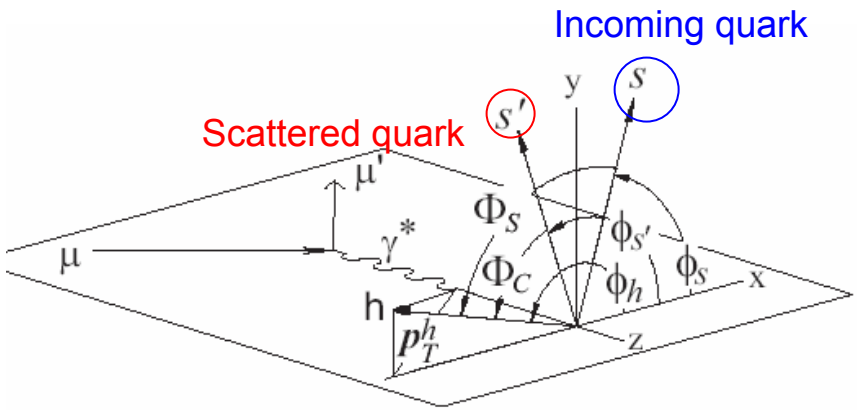
Measured single spin asymmetry:

$$A^m = \frac{N^{\uparrow}(\Phi)_{Coll(Siv)} - R \cdot N^{\downarrow}(\Phi)_{Coll(Siv)}}{N^{\uparrow}(\Phi)_{Coll(Siv)} + R \cdot N^{\downarrow}(\Phi)_{Coll(Siv)}} \propto A_{Coll(Siv)} \sin(\Phi)_{Coll(Siv)}$$

with normalization factor $R = \frac{N^{\uparrow}_{h,tot}}{N^{\downarrow}_{h,tot}}$

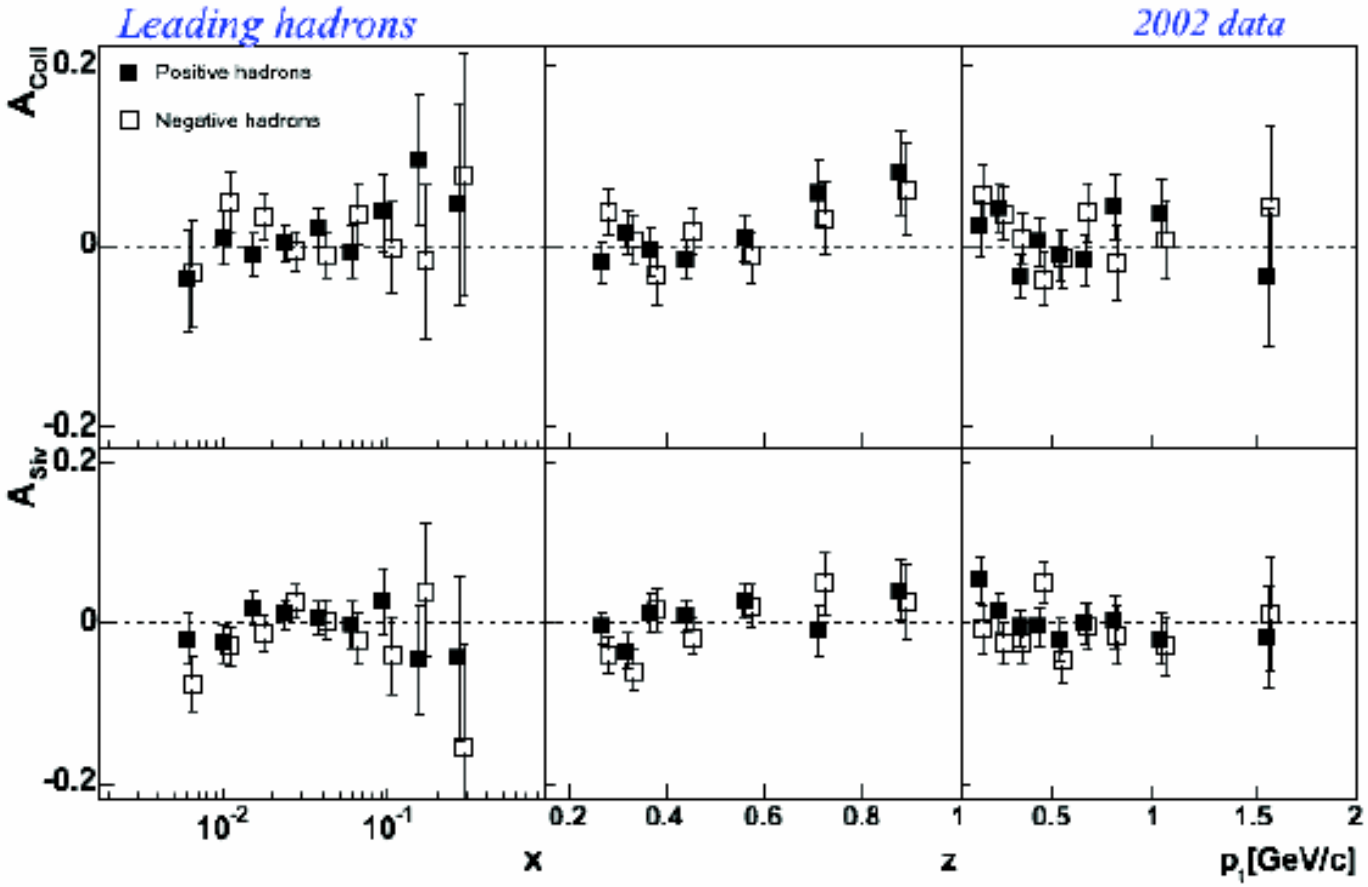
$\Phi_{Coll} = \Phi_h - \Phi_{s'}$

$\Phi_{Siv} = \Phi_h - \Phi_s$



A_{Coll} and A_{Siv} for leading hadrons

- Single spin asymmetries from 2002 data – 20% of total data sample
- Leading hadrons defined by z > 0.25



COMPASS

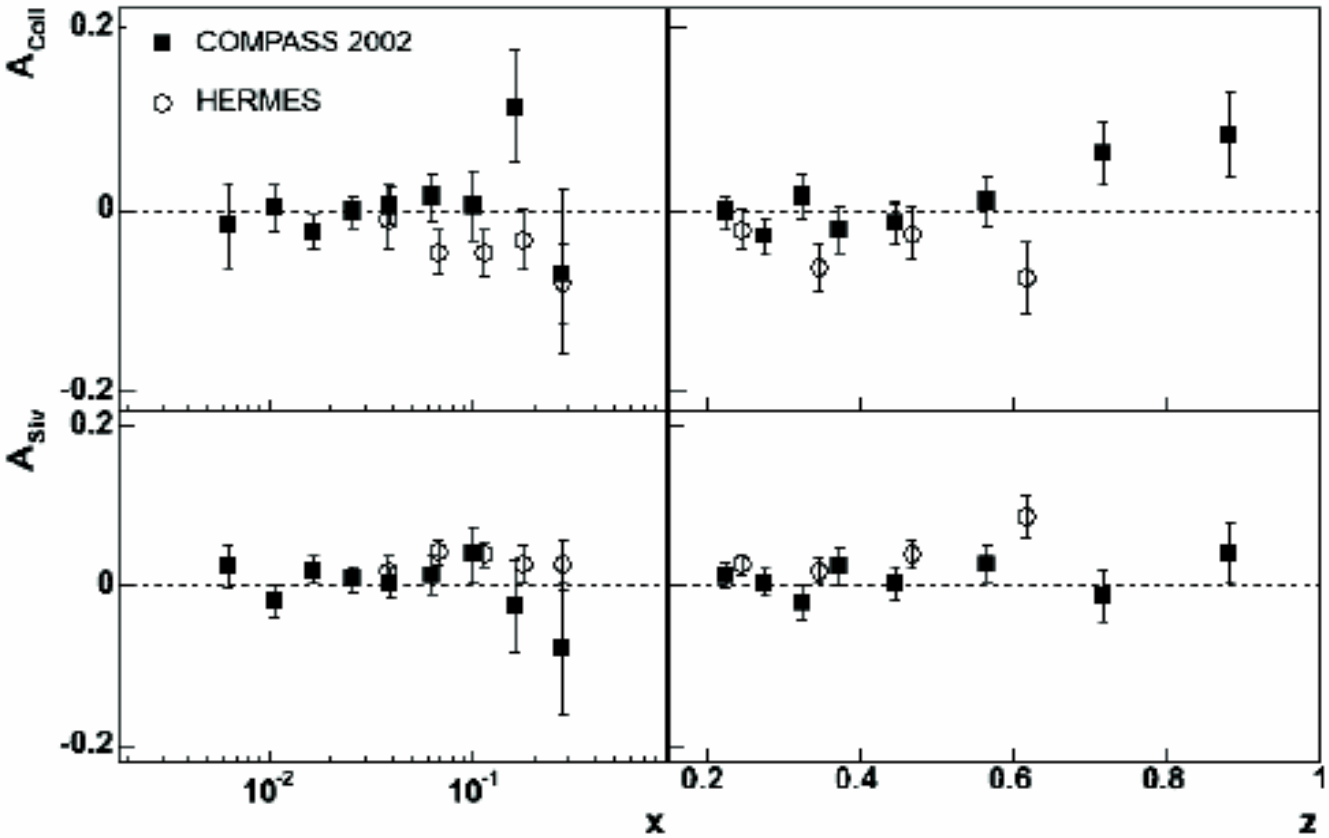
asymmetries consistent with zero

Marginal Collins effect seen at large z

Analysis also done for sample with all hadrons (factor ~1.5 more hadrons)

results consistent with leading hadron analysis

A_{Coll} and A_{Siv} for positive hadrons



COMPASS –deuteron

PRL 94 (2005) 202002

All hadrons selected with $z > 0.2$

HERMES- proton

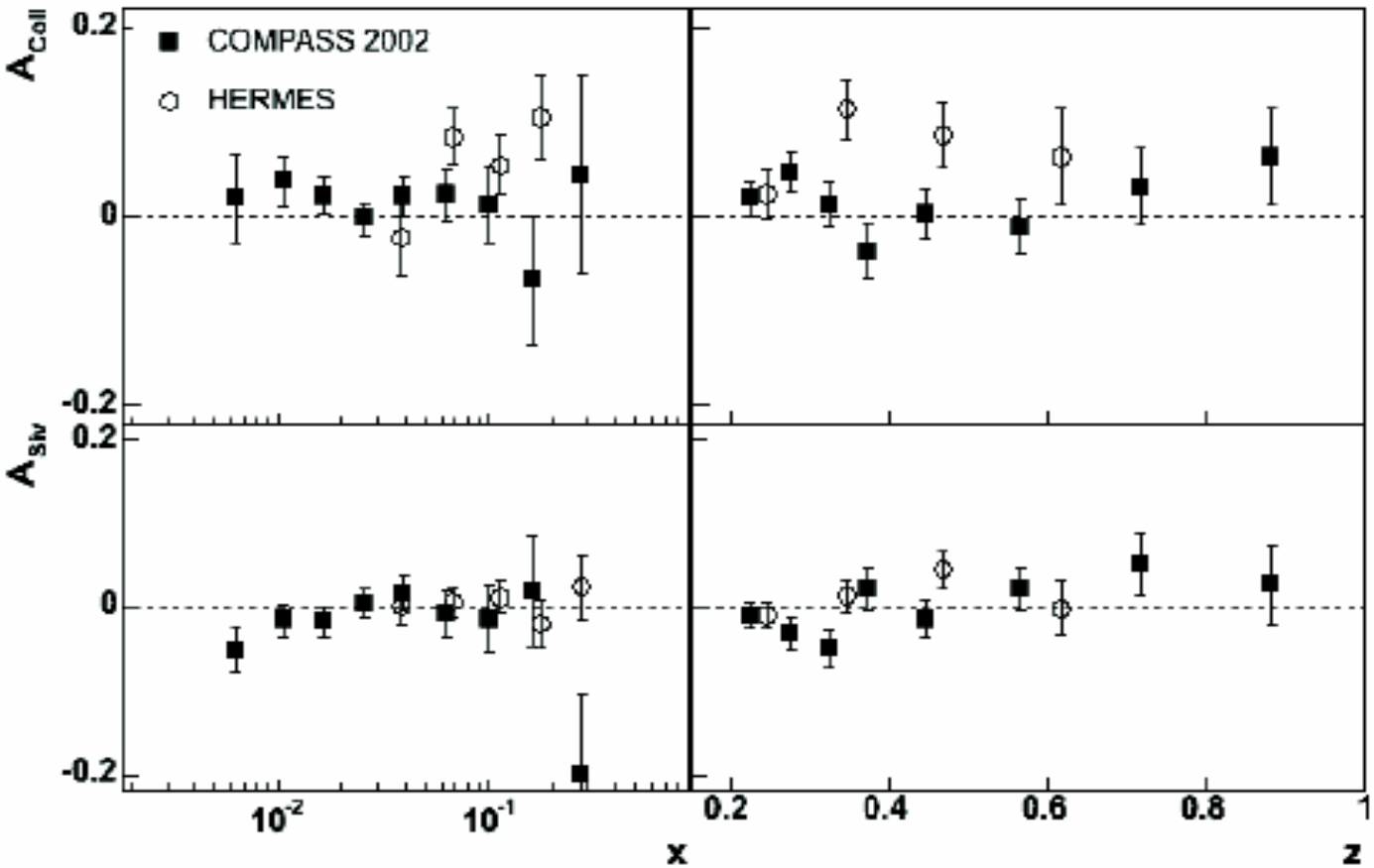
PRL 94 (2005) 012002

Pion production

Measurement at COMPASS :

- extend the kinematic region to lower x and higher z
- no effect except at large z

A_{Coll} and A_{Siv} for negative hadrons

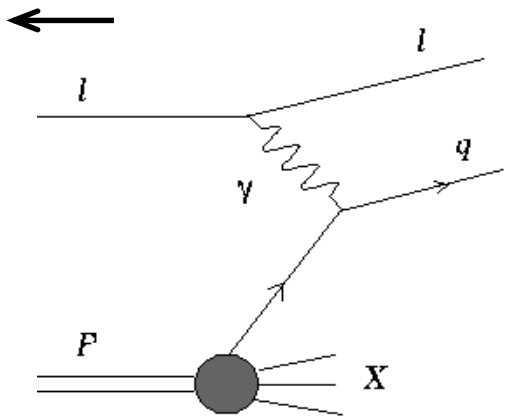


A_{Siv} is zero for COMPASS and HERMESS

- COMPASS asymmetries consistent with zero for positive and negative hadrons
- deuteron target vs HERMES proton target → possible effect cancellation

Measurement with longitudinally polarized target

Lepton



Nucleon

Measured asymmetry

$$A^{\mu d} = \frac{\Delta\sigma}{2\sigma} = \frac{\sigma^{\leftarrow\Rightarrow} - \sigma^{\leftarrow\Leftarrow}}{\sigma^{\leftarrow\Rightarrow} + \sigma^{\leftarrow\Leftarrow}}$$

$$A_1^{\gamma d} \cong \frac{A^{\mu d}}{D}$$

Spin-dependent structure function :

$$g_1 = \frac{F_2}{2x(1+R)} A_1^{\gamma d}$$

where :

F_2 spin-independent structure function and $R = \frac{\sigma_L}{\sigma_T}$

Kinematic range

Data sample :

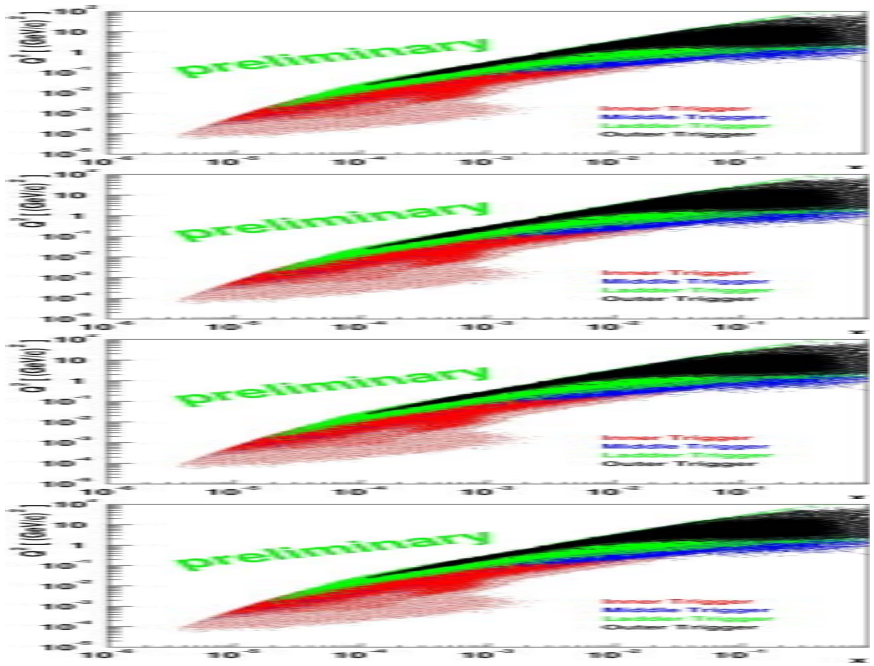
2002+2003 data

(71% 2003 year)

Cuts :

$Q^2 > 1\ GeV^2$

$0.1 < y < 0.9$



After cuts : 34M DIS events

Excellent for non-perturbative & perturbative physics:

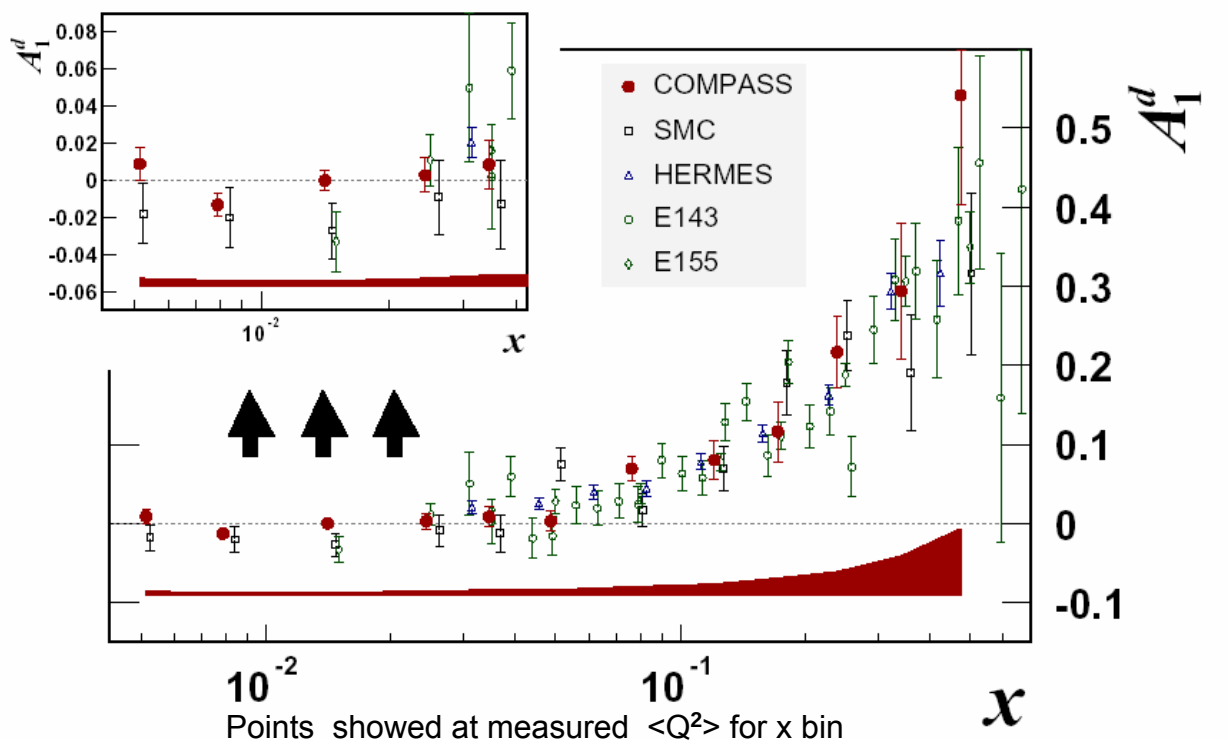
- small x
- very small Q^2 → $Q^2 > 100\ GeV^2$

Result on A_1^d

Published:

PLB 612 (2005) 154

$$A_1 = \frac{1}{2\langle P_t P_b f D \rangle}\left(\frac{N_u - N_d}{N_u + N_d} - \frac{N'_u - N'_d}{N'_u + N'_d}\right)$$

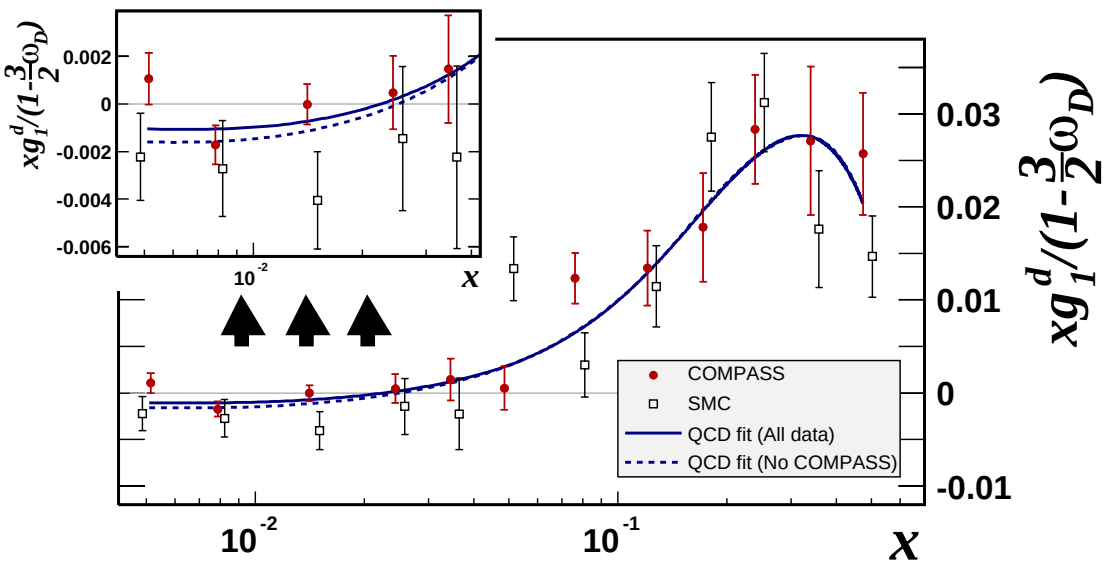


Points showed at measured $\langle Q^2 \rangle$ for x bin

→ most precise in the region x < 0.03 (statistical precision improved by factor 2.5)

→ A_1^d less negative in this region

Impact of COMPASS g_1 (x) on QCD fit



First moment of g1(x) evaluated at Q^2= 4 GeV^2:

points showed at measured Q^2

$$\int_0^1 \Delta\Sigma(x)\mathrm{d}x = 0.237^{+0.024}_{-0.029}$$

including COMPASS data

$$= 0.202^{+0.042}_{-0.077}$$

without COMPASS data

→ precision on ΔΣ improved by a factor 2

→ ΔG remains unchanged

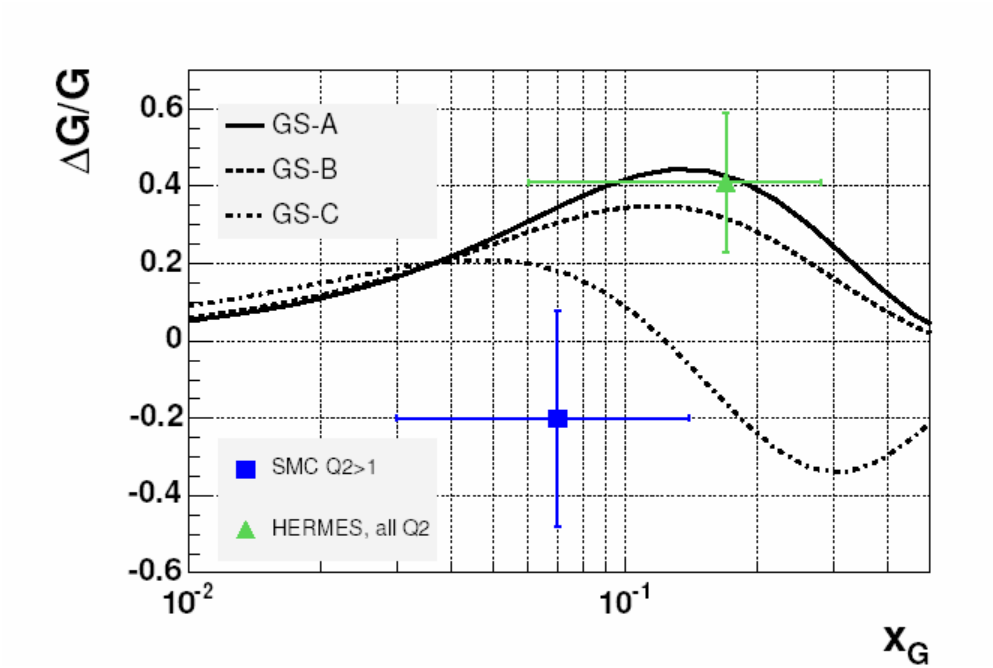
Access to gluon polarization $\Delta G/G$

DIS inclusive data sensitivity to ΔG through Q^2 dependence of $g_1(x,Q^2)$

→ Direct measurement of ΔG important

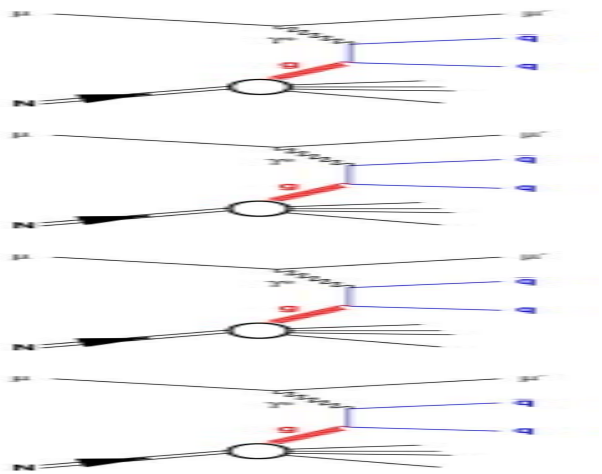
HERMES, A.Airapetian et al.,
Phys.Rev.Lett.84, 2584 (2000).

SMC, B.Adeva et al.,
Phys.Rev.D 70, 0102002 (2004)



How to measure $\Delta G/G$ at COMPASS ?

Photon-Gluon Fusion process (PGF)



- q= u,d,s pairs of hadrons with large p_T
  - $\rightarrow$ $Q^2>1$ GeV^2
  - $\rightarrow$ $Q^2<1$ GeV^2
    (large statistics for $Q^2<1$GeV^2)

- q = c charmed meson production

The charm at COMPASS:

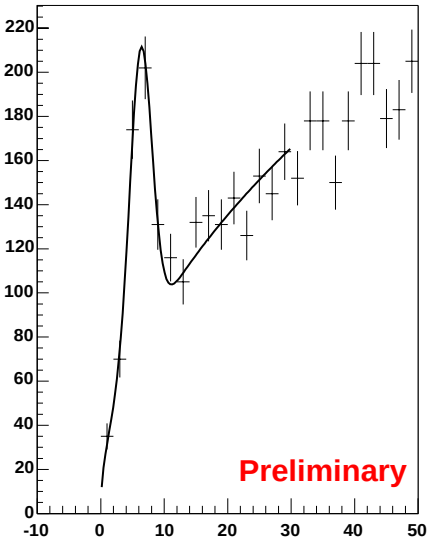
$$D^0 \rightarrow K\pi$$

$$D^* \rightarrow (K\pi)\pi$$

$$A^{lN} = \frac{\Delta\sigma}{2\sigma} = \frac{\sigma^{\leftarrow\Rightarrow} - \sigma^{\leftarrow\Leftarrow}}{\sigma^{\leftarrow\Rightarrow} + \sigma^{\leftarrow\Leftarrow}} \propto \frac{\Delta G}{G}$$

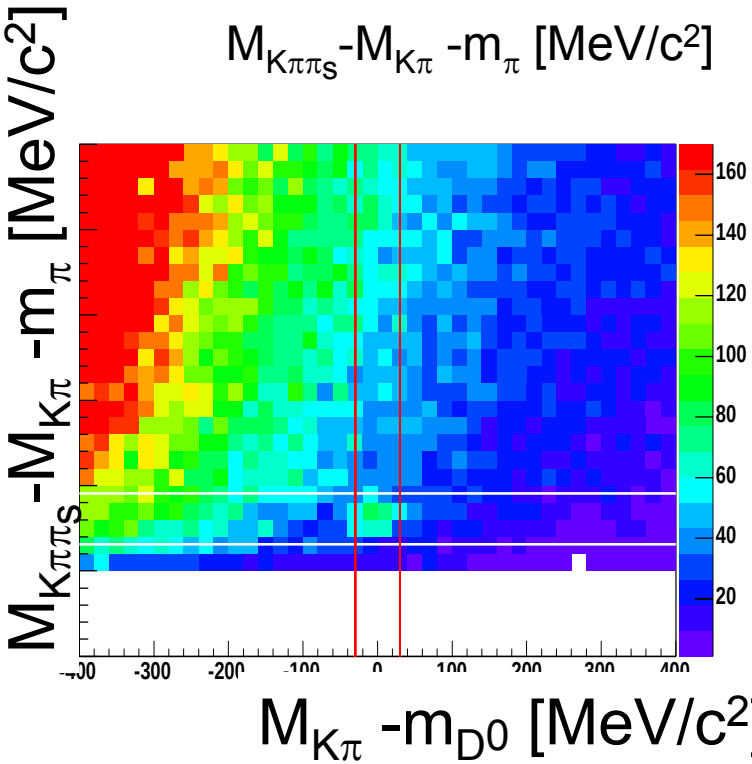
Plots for 2002 data

Tagging D^* by D^0

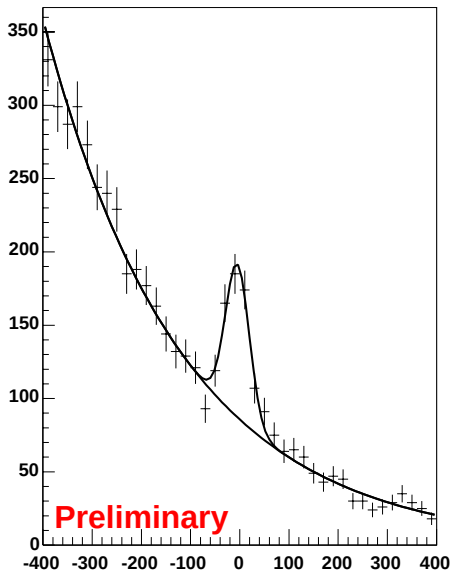


$M_{K\pi\pi_s}-M_{K\pi}-m_\pi$ [MeV/c^2]

D^* signal after cut on m(D^0) 60 MeV around D^0 peak



$M_{K\pi}-m_{D0}$ [MeV/c^2]

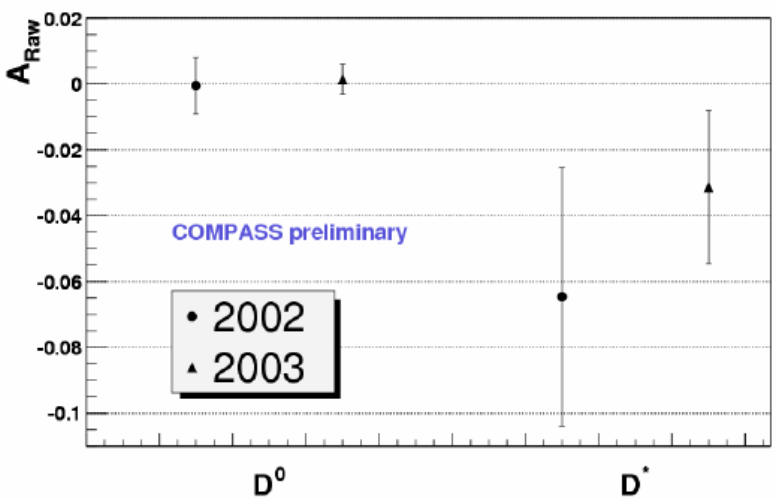


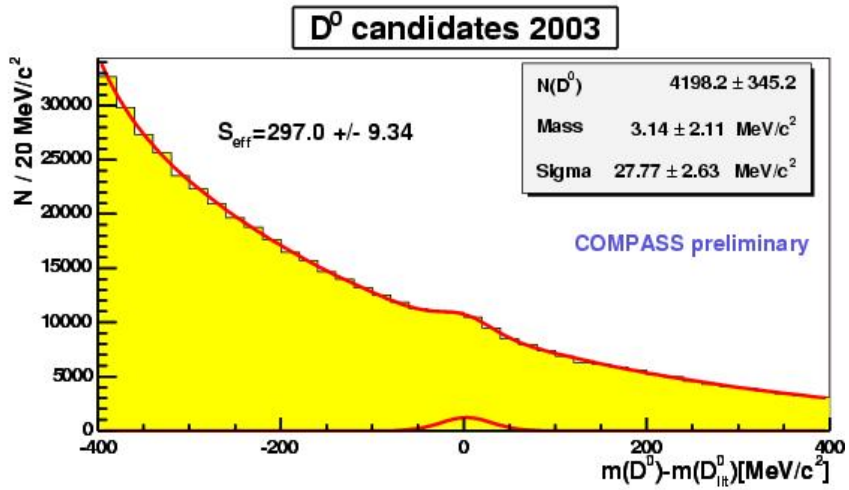
D^0

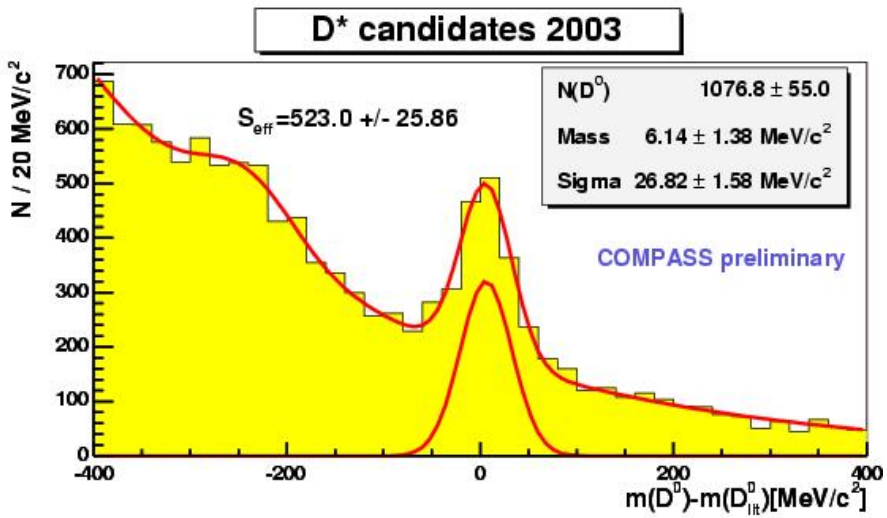
$M_{K\pi}-m_{D0}$ [MeV/c^2]

Asymmetry for charm production

$$A_{Raw}^{m} = \frac{N_m^{\uparrow\downarrow} - N_m^{\uparrow\uparrow}}{N_m^{\uparrow\downarrow} + N_m^{\uparrow\uparrow}} = \frac{S}{S+B}\langle P_\mu P_T f a_{LL}\rangle \frac{\Delta G}{G}$$



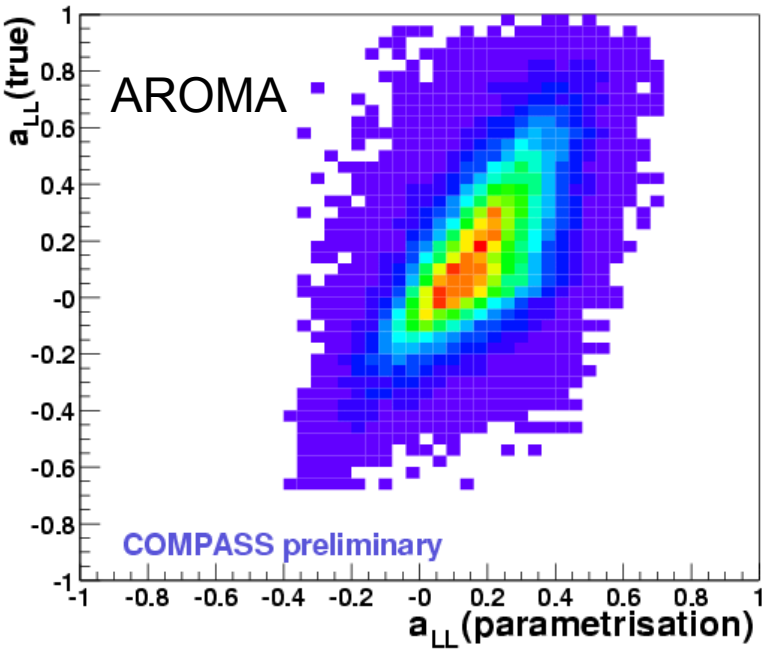


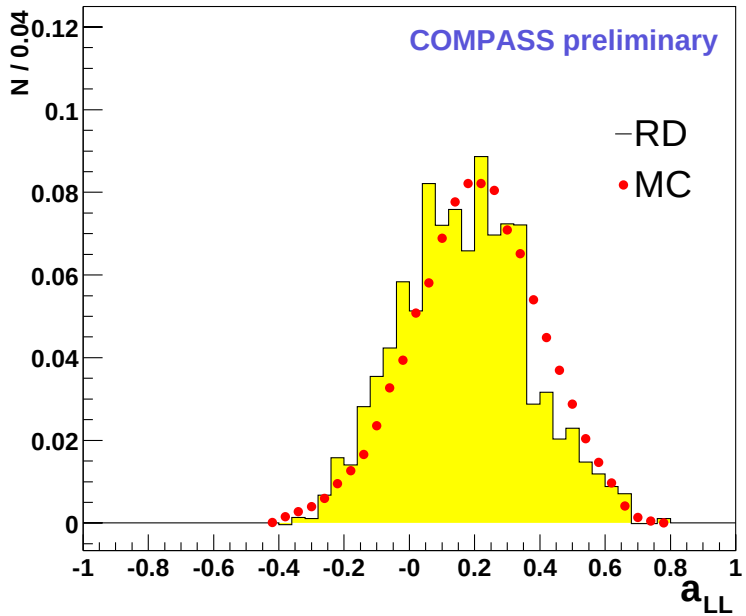


For $\Delta G/G$ a_{LL} for PGF is needed

Partonic asymmetry for PGF

1. parameterised in AROMA $a_{LL}(y,z_D,p_T)$
2. calculated from data using parameterization from MC simulation

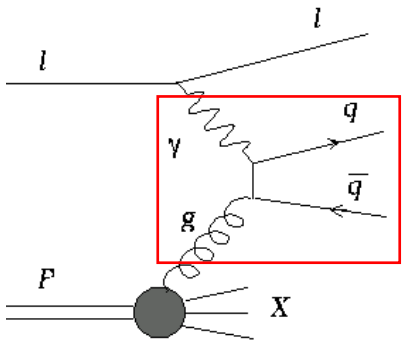




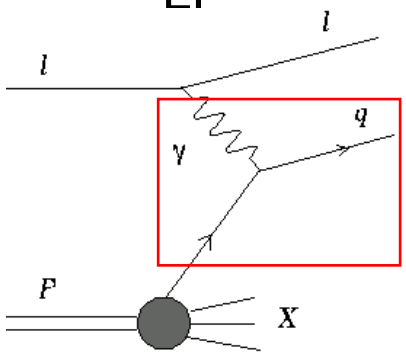
$\Delta G/G$ from open charm will be shown soon from 2002/2003 data

ΔG/G from high-pt hadron pairs $Q^2>1GeV^2$

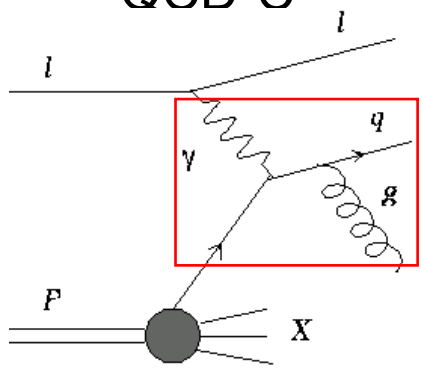
PGF



LP



QCD-C



$$\frac{A_{\parallel}^{lN\to lhhX}}{D} = \frac{\Delta G}{G}\left\langle \frac{\hat{a}_{LL}^{PGF}}{D}\right\rangle R^{PGF} + \frac{\Delta q}{q}\left(\left\langle \frac{\hat{a}_{LL}^{LP}}{D}\right\rangle R^{LP} + \left\langle \frac{\hat{a}_{LL}^{QCDC}}{D}\right\rangle R^{QCD\text{-}C}\right)$$

$\frac{\Delta q}{q} \propto A_1$ taken from inclusive DIS measurements

$\langle \hat{a} \rangle_{LL}$ the asymmetry for hard sub-process

R the fraction of events

} Provided by MonteCarlo

Result on high-p_T asymmetry $Q^2>1$ GeV^2

Data sample: 2002+2003 data

Kinematic cuts:

- $Q^2 > 1\text{GeV}^2$ ~ 10% data
- $0.4 < y < 0.9$
- $x < 0.05$

Selection for both hadrons :

- $x_F>1$ and $z> 0.1$
- $p_T > 0.7$ GeV
- $p_{T1}^2+ p_{T2}^2 > 2.5\ \text{GeV}^2$

$$\frac{A_{\parallel}}{D} = -0.015 \pm 0.080(\text{stat.}) \pm 0.013(\text{sys.})$$

Using R_{PGF} =0.34±0.07(sys.) from LEPTO:

Systematic error R_{PGF} accounts for:

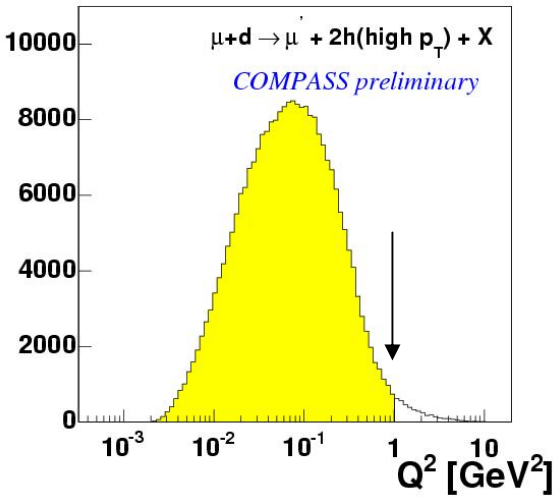
→ Sensitivity to $p_{T1}^2+ p_{T2}^2$ cut

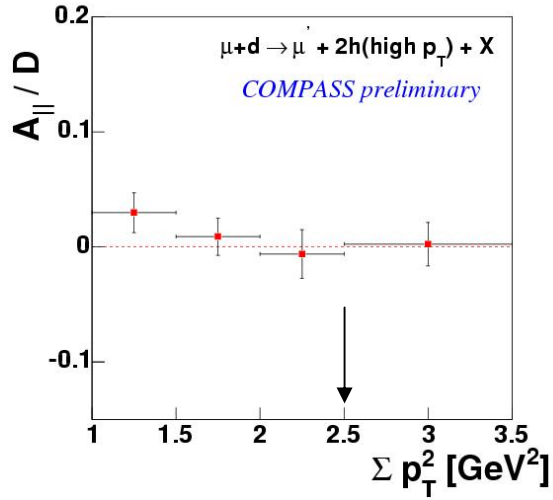
→ Default and modified set of fragmentation parameters

$$\frac{\Delta G}{G} = 0.06 \pm 0.31(\text{stat.}) \pm 0.06(\text{sys.}) \ \text{at} < x_g >= 0.13 \pm 0.08$$

Pairs of high-pt hadrons for $Q^2<1GeV^2$

Large data sample for $Q^2 < 1\ GeV^2$





Combined analysis for 2002+2003:

$$\frac{A_{\parallel}}{D} = 0.002 \pm 0.019(\text{stat.}) \pm 0.003(\text{sys.})$$

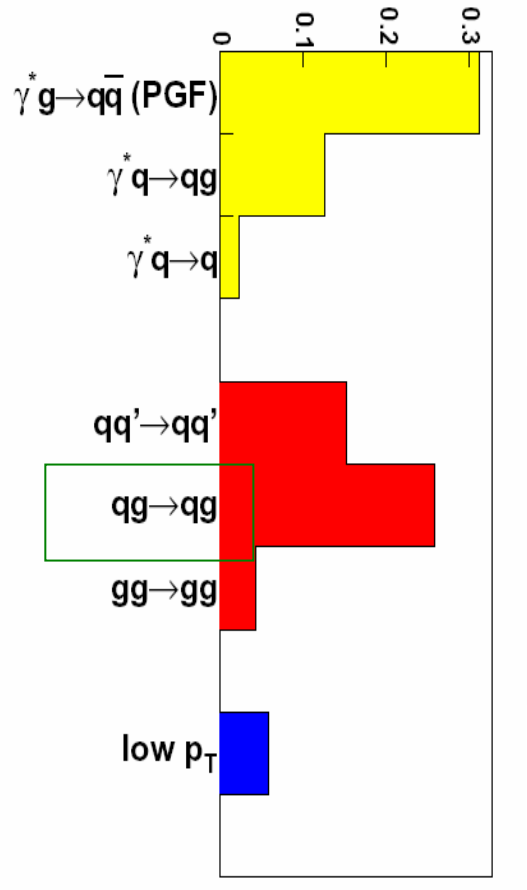
with D=<0.64>

Determination of $\Delta G/G$ from measured asymmetry

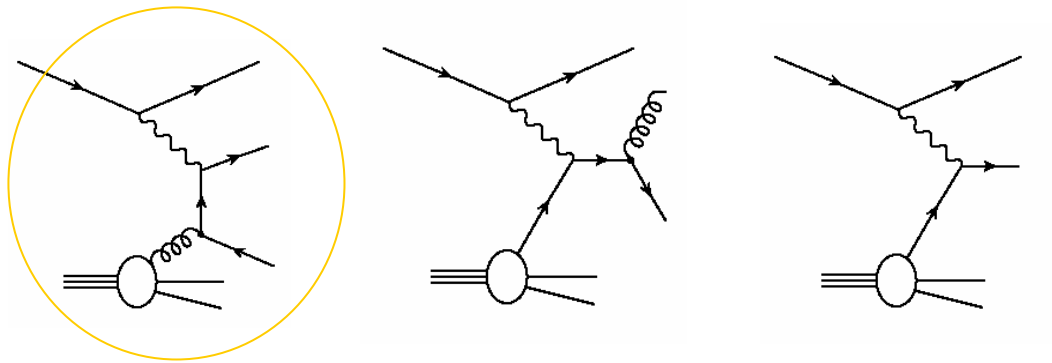
based on PYTHIA simulations

Pythia simulations for $Q^2 < 1 GeV^2$

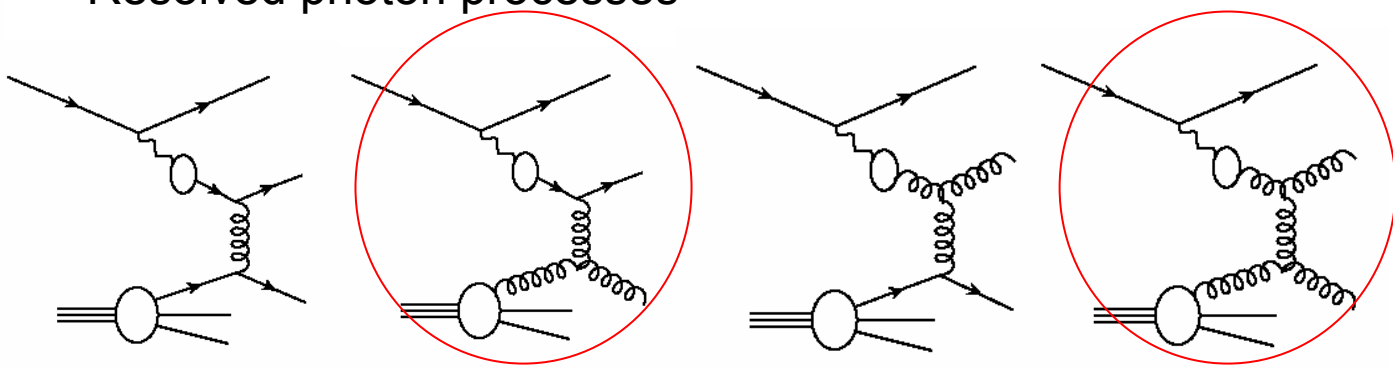
Contribution from subprocesses



Direct processes



Resolved photon processes



For $Q^2 < 1$ Gev^2 additional processes contribute:

resolved photon processes and low p_T scattering

Asymmetry calculation for low Q^2

$$\frac{A_{\parallel}}{D} = R_{pgf}\left\langle \frac{\hat{a}_{pgf}}{D} \right\rangle \left(\frac{\Delta G}{G}\right)^{d}$$

$$+ R_{qcdc}\left\langle \frac{\hat{a}_{qcdc}}{D} \right\rangle \left(\frac{\Delta q}{q}\right)^{d}$$

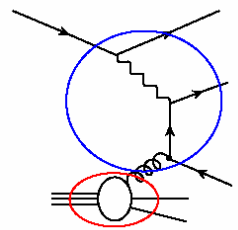
$$+ \cancel{R_{lodis}\left\langle \frac{\hat{a}_{lodis}}{D} \right\rangle \left(\frac{\Delta q}{q}\right)^{d}}$$

$$+ R_{qq'}\left\langle \hat{a}_{qq'} \right\rangle \left(\frac{\Delta q}{q}\right)^{d}\left(\frac{\Delta q'}{q'}\right)^{\gamma}$$

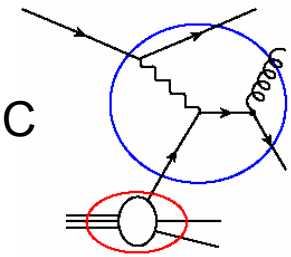
$$+ \ldots..$$

$$+ \cancel{\textit{Low-pT}}$$

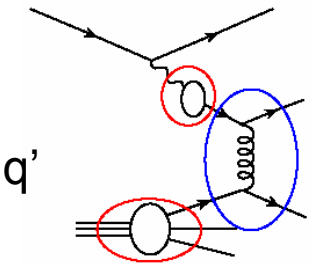
PGF



QCDC

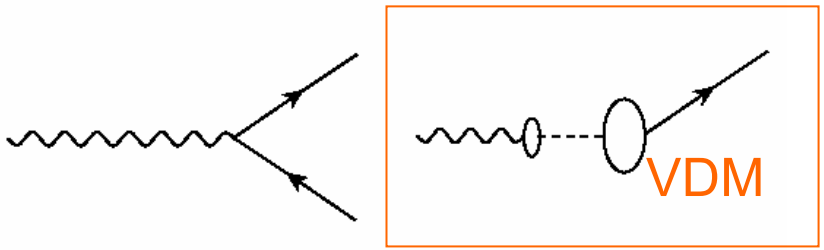


qq’



- LO DIS and low p_T processes were neglected
- uncertainty due to spin content of resolved photons

Quark polarization in the photon



$$\Delta q^{\gamma} = \Delta q^{\gamma}_{q\bar{q}} + \Delta q^{\gamma}_{VMD}$$

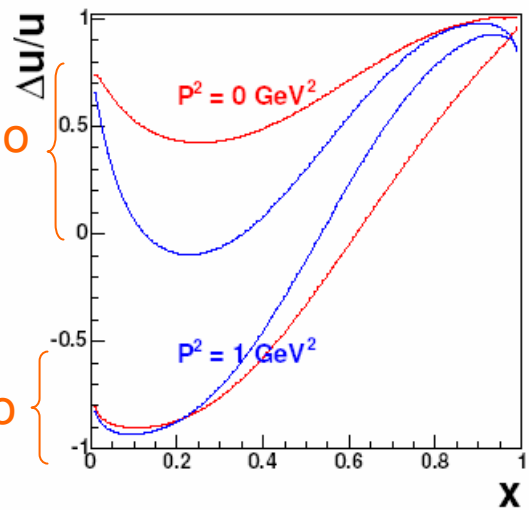
→ $\Delta q^{\gamma}_{q\bar{q}}$: QED+QCD

→ for VDM use min. and max. scenarios

$$-q^{\gamma}_{VMD} \leq \Delta q^{\gamma}_{VMD} \leq q^{\gamma}_{VMD}$$

max. scenario

min. scenario



to estimate the contribution of VDM

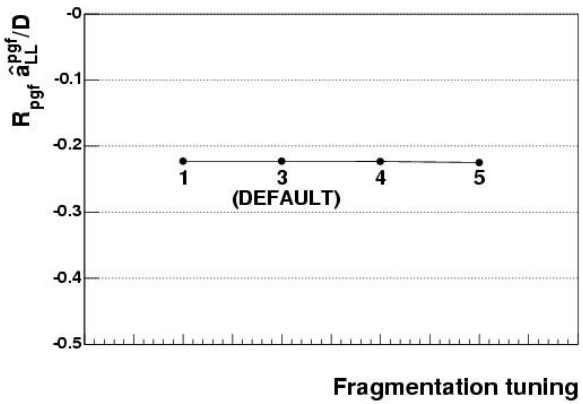
for the ΔG/G evaluation

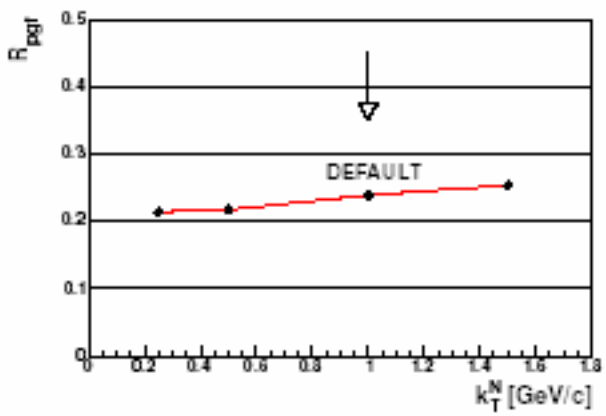
(Glück, Reya, Sieg)

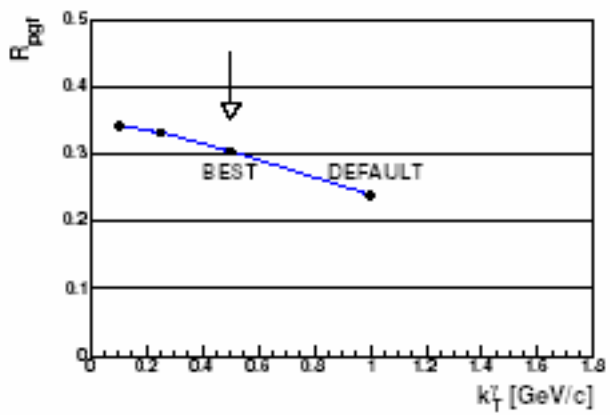
Monte Carlo systematic error

- Accounts for NLO effect:
  - renormalization/factorization scale dependence
  - parton showers (on/off)

- Hadron p_T description in MC
  - Parton fragmentation
  - k_T of partons in nucleon and photon

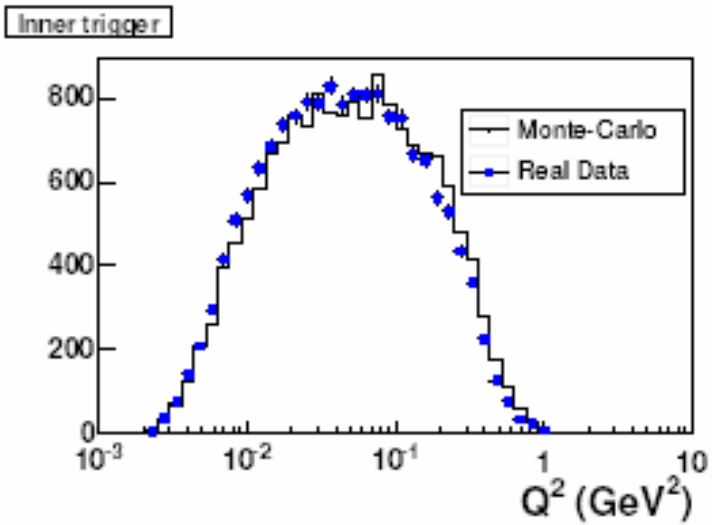


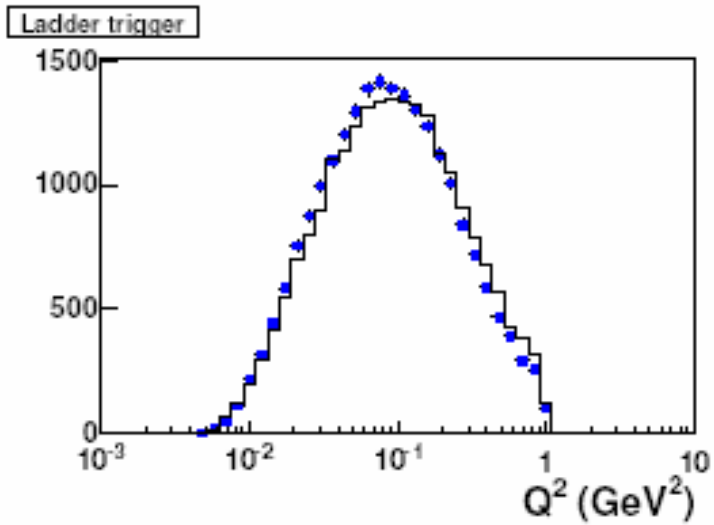


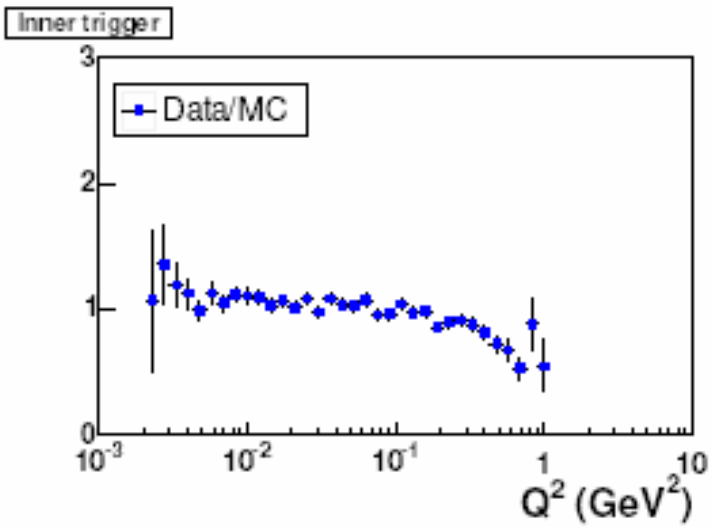


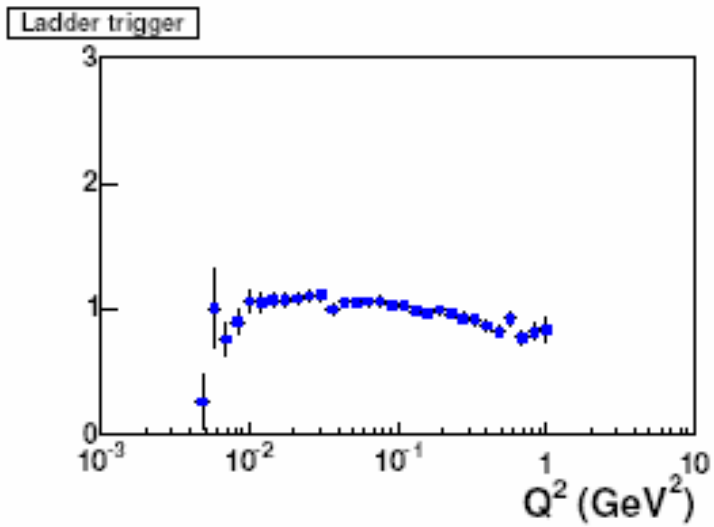
Data and Monte Carlo

Kinematic variables



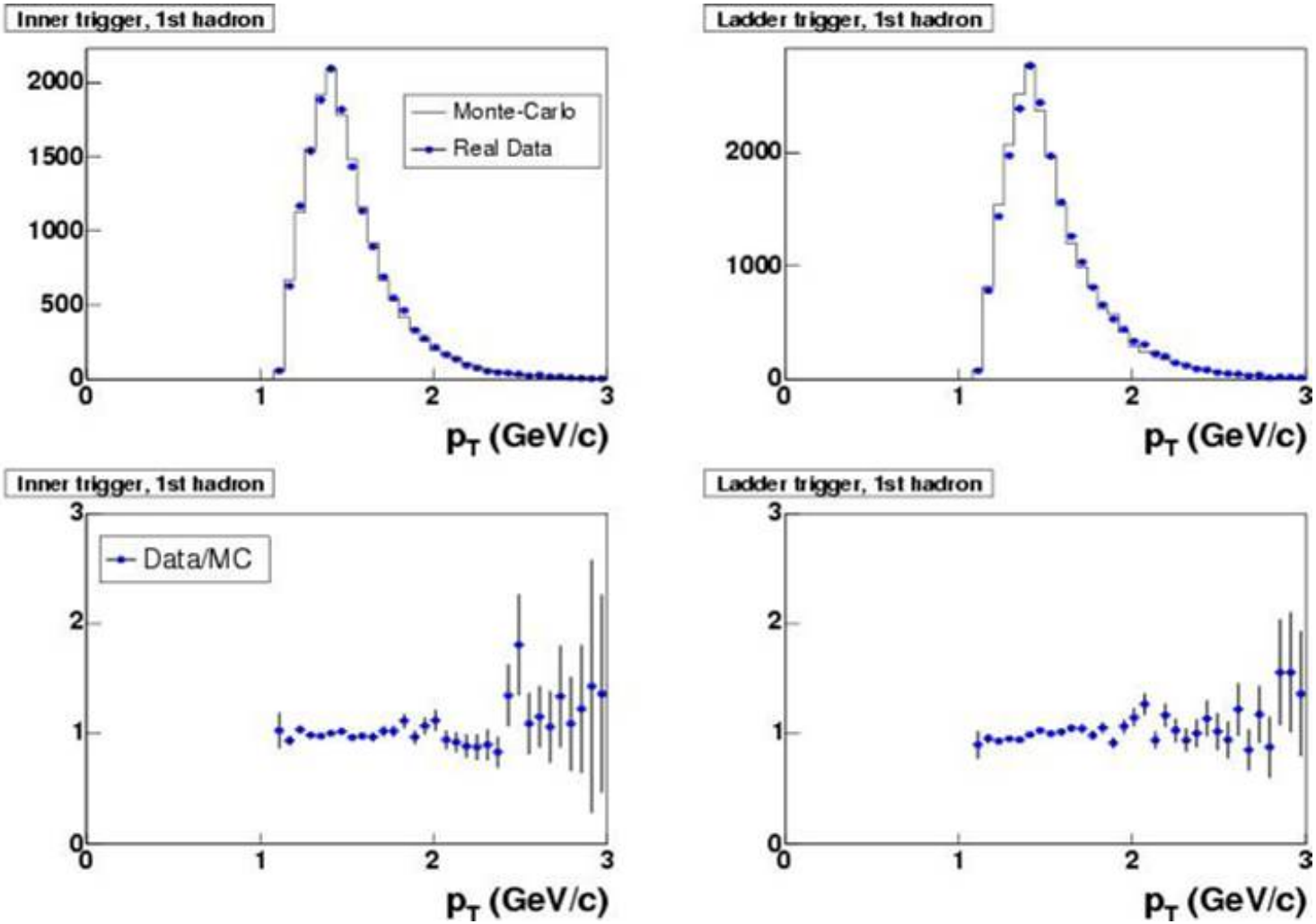






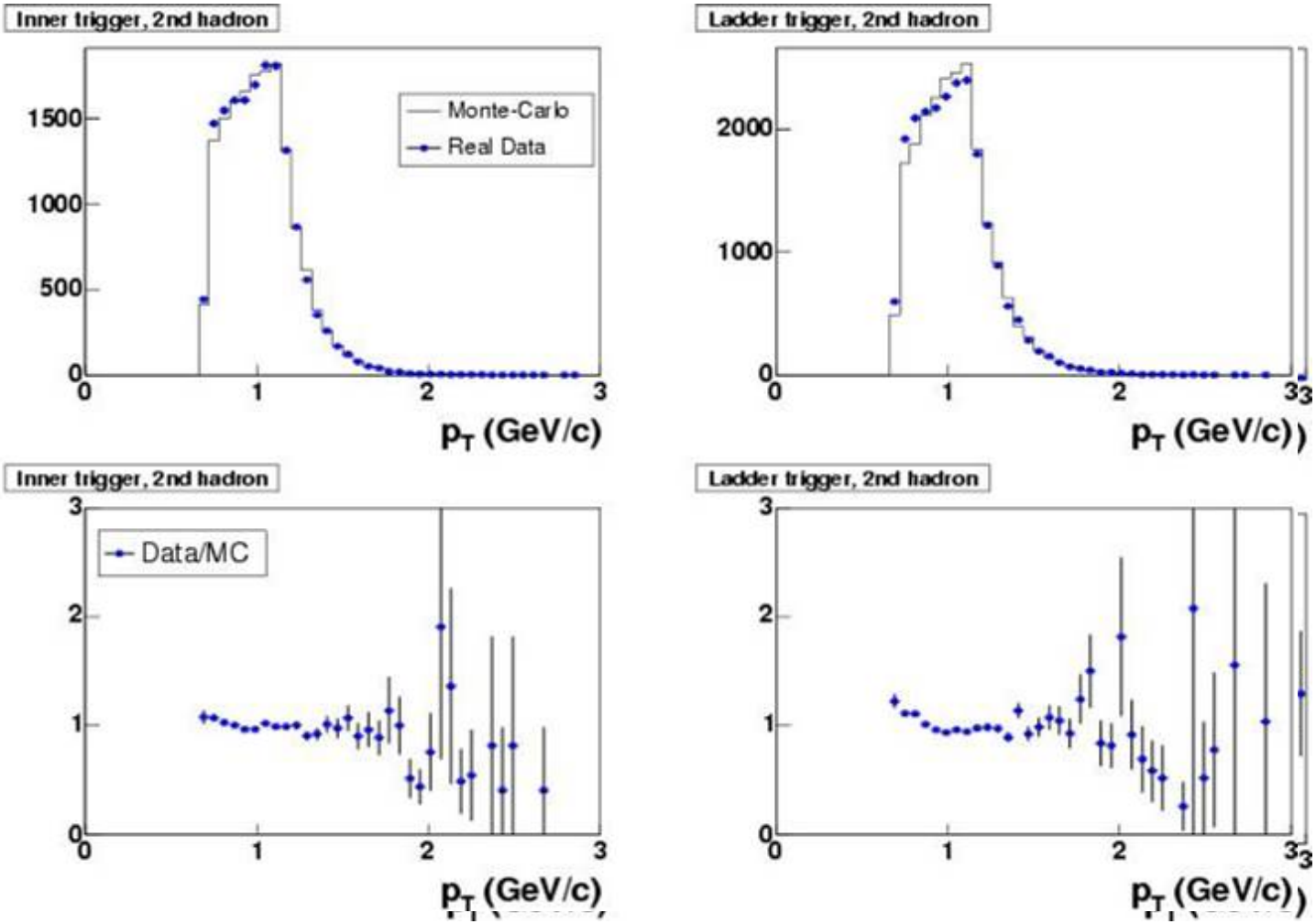
Data and Monte Carlo

hadron with highest p_T



Data and Monte Carlo

second selected hadron

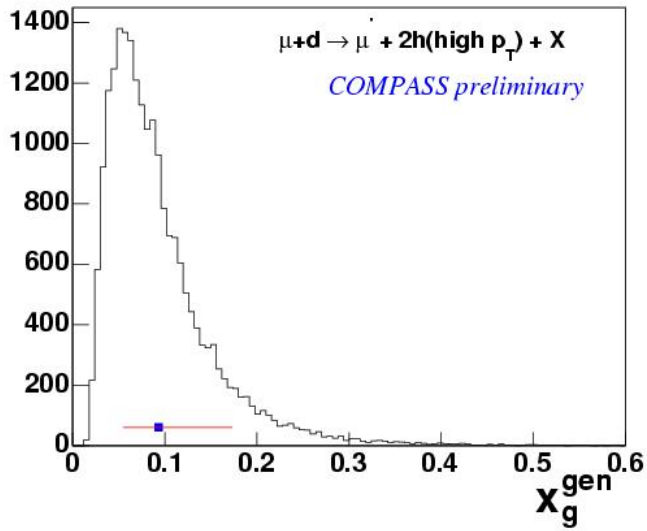


$\Delta G/G$ from high-pt hadron pairs for low Q^2

For 2002+ 2003 data :

$$\frac{\Delta G}{G} = 0.024 \pm 0.089(stat.) \pm 0.057(syst.).$$

at $<x_g>=0.095$

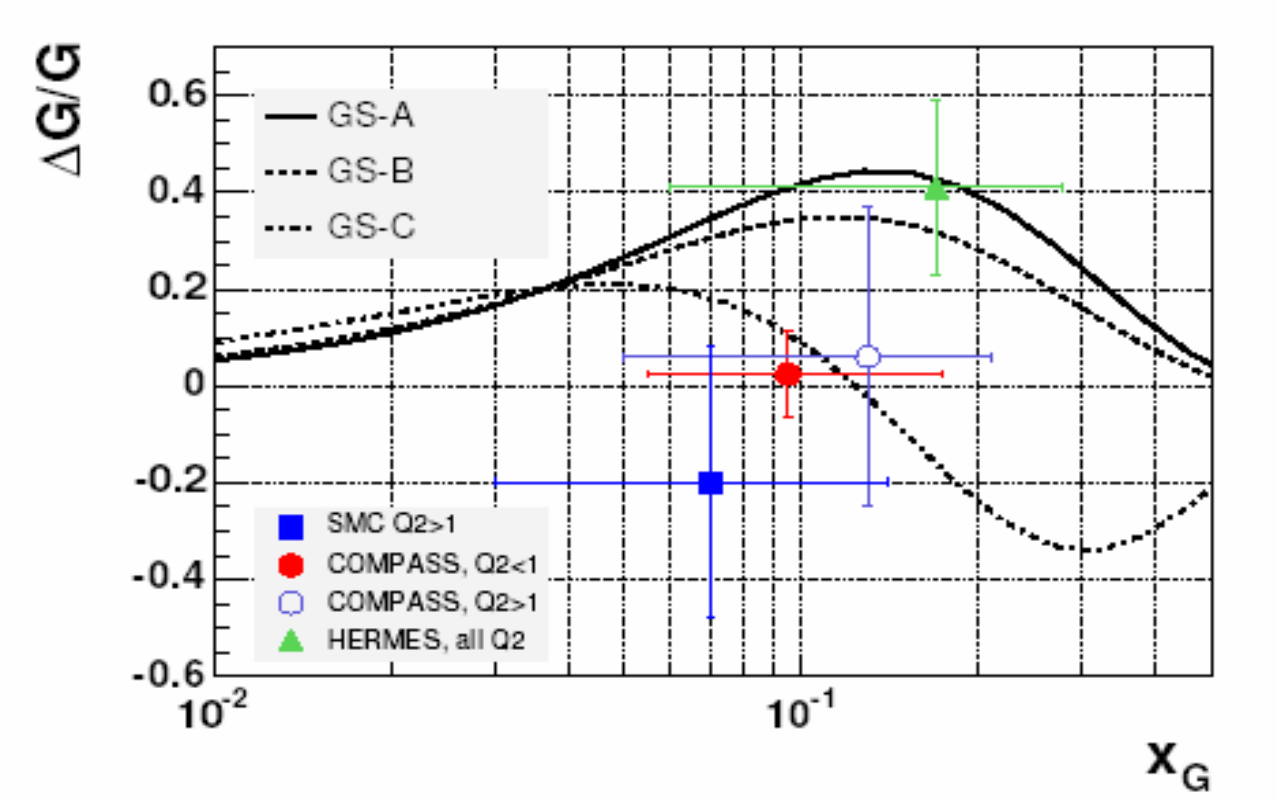


obtained by averaging results for minimum and maximum scenario in VDM :

$$\left(\frac{\Delta G}{G}\right)_{min} = 0.016 \pm 0.068(stat) \pm 0.011(exp.syst) \pm 0.018(MC.syst)$$

$$\left(\frac{\Delta G}{G}\right)_{max} = 0.031 \pm 0.089(stat) \pm 0.014(exp.syst) \pm 0.052(MC.syst)$$

Results or high-pt hadrons pairs



- Both COMPASS results consistent with zero
- the most precise measurement of $\Delta G/G$ for low Q^2

Summary

→ COMPASS run 2002-04 brings first physics results :

PLB 612 (2005) 154: "Measurement of the spin structure function of the deuteron in DIS region"

PRL 94 (2005) 202002: "First measurement of the transverse spin asymmetries of the deuteron in semi-inclusive deep inelastic scattering"

→ Results on $\Delta G/G$ data 2002/2003:

- results for D^0 analysis will be presented on the summer conferences
- from high-pT $Q^2<1GeV^2$ $\Delta G/G=0.02\pm0.09(stat.)\pm0.06(sys.)$ $x_G=0.095$
- from high-pT $(Q^2>1\ GeV^2)$ $\Delta G/G=0.06\pm0.31(stat.)\pm0.06(sys.)$ $x_G=0.13$

→ Expected precision on $\Delta G/G$ data 2002-2004

- from high-p_T ($Q2<1GeV^2$) $\sigma(\Delta G/G) \sim 0.05$
- from high-p_T $(Q^2>1\ GeV^2)$ $\sigma(\Delta G/G) \sim 0.16$
- open charm $\sigma(\Delta G/G) \sim 0.24$

→ COMPASS will resume data taking 2006

→ continue data taking ≥ 2010 with aim to study GPDS with DVCS and exclusive meson production on hydrogen target (+recoil detector)